Flavoured Co-annihilations

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D. Choudhury, R. Garani, S. Vempati arXiv:1104.4467 [hep-ph]

Neutralino Dark Matter

Supersymmetric theories have **a few** dark matter candidates depending on model of SUSY breaking

Neutralino, Gravitino, axino, saxino, etc..

The most popular of them is the minimal Supergravity/CMSSM model with neutralino as the LSP

The model has just $\mathrm{four}^{\pm}$ parameters which are

$$m_0 \quad M_{1/2} \quad \tan\beta \quad \mathrm{sg}(\mu) \quad A_0$$

The entire mass spectrum and couplings are determined by these parameters

Neutralino Mass matrix

$$\mathcal{L} \supset \frac{1}{2}\,\Psi_N \mathcal{M}_N \Psi_N^T \ + H.c \qquad\qquad \Psi_N = \{\tilde{B},\ \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0\}$$

$$\mathcal{M}_N = \begin{pmatrix} M_1 & 0 & -M_Z c\beta\ s\theta_W & M_Z s\beta\ s\theta_W \\ 0 & M_2 & M_Z c\beta\ c\theta_W & M_Z s\beta\ c\theta_W \\ -M_Z c\beta\ s\theta_W & M_Z c\beta\ c\theta_W & 0 & -\mu \\ M_Z s\beta\ s\theta_W & -M_Z s\beta\ c\theta_W & -\mu & 0 \end{pmatrix}$$

Diagonalising $\quad N^* \cdot M_{\tilde{N}} \cdot N^\dagger = \mathrm{Diag.}(m_{\chi_1^0}, m_{\chi_2^0}, m_{\chi_3^0}, m_{\chi_4^0})$

$$\chi_1^0 = N_{\tilde{B}1}\tilde{B} + N_{\tilde{W}1}\tilde{W}^0 + N_{\tilde{H}_1 1}\tilde{H}_1^0 + N_{\tilde{H}_2 1}\tilde{H}_2^0$$

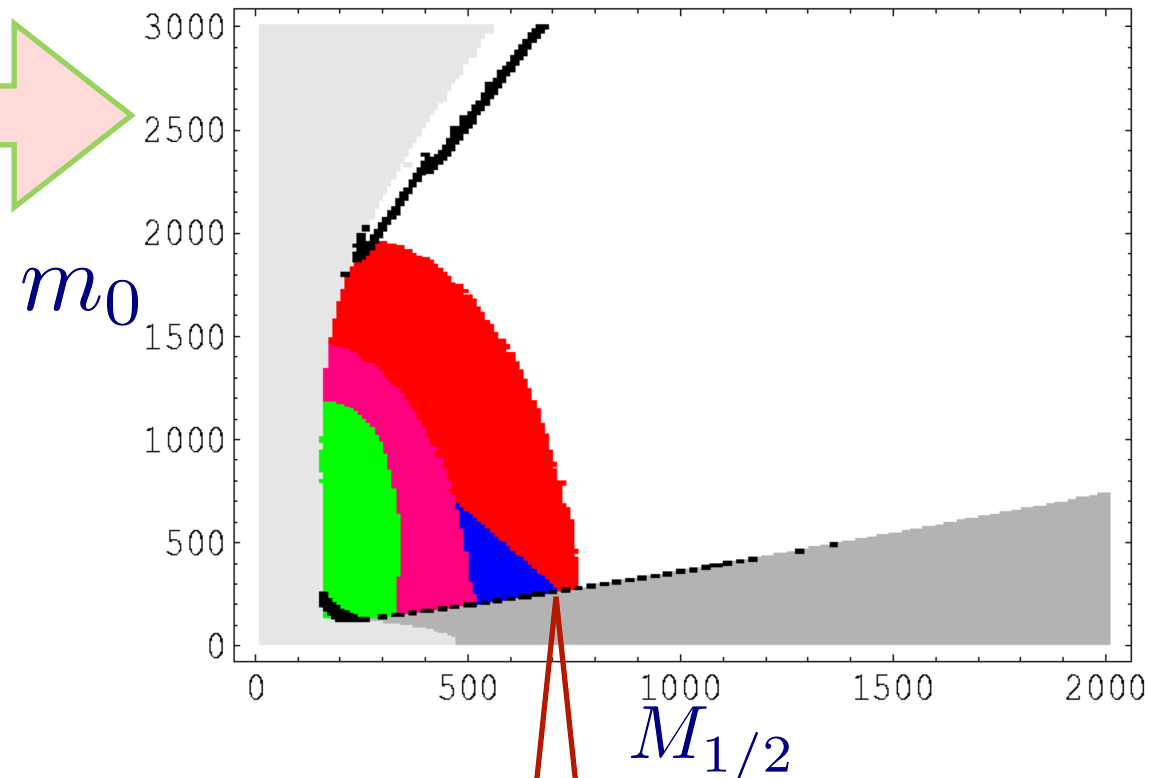
The composition of the lightest neutralino determines the regions where the relic density is satisfied

Three main regions

Focus Point/HP Region

$$m_0 \gg M_{1/2}$$

significant higgsino component



Djouadi, Drees and Kneur, 2006

$\tan\beta = 30$

$A_0 = 0$

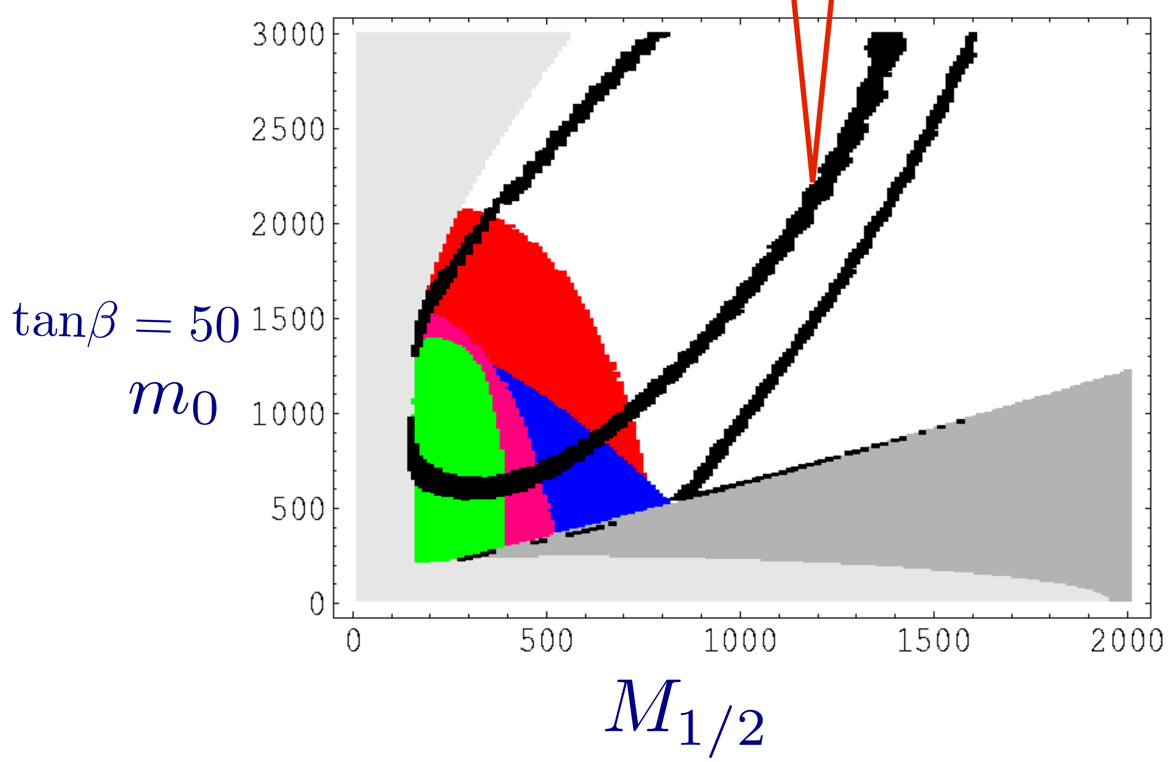
$m_t = 173.2\mathrm{GeV}$

Funnel Region

$$2m_{\chi_0^1} = m_A$$

$$m_{\chi_0^1} \approx m_{\tilde{\tau}_R}$$

Stau-Coannihilation Region



I have not discussed revival of bulk and stop co-annihilation regions with large A-terms

Completely different phenomenology

But TWO POINTS

The scale of mediation of supersymmetry breaking is close to Planck Scale. The GUT scale is at least two orders of magnitude lower than that.

$$M_{\rm Pl} = 10^{18}\,\mathrm{GeV} \quad \Rightarrow \quad M_{\rm GUT} = 2.10^{16}\,\mathrm{GeV}$$

*It is well known that RG running between these two scales can significantly modify the low energy spectrum, especially the flavour sector

Hall, Kostelcky, Raby, 87
Barbieri, Hall, Strumia, 96

*Neutrino masses are well established now. Seesaw mechanism needs to be incorporated. Fits naturally in SO(10) models. Has again, large effects in weak scale physics in terms of flavour violation.

Masiero Borzumati 86
Casas Ibarra 01

No reason to expect that these effects would not modify the dark matter regions.

GUT Effects on Dark Matter

(1) Through flavour violating entries in the slepton mass matrix with and without seesaw (Modifies Co-annihilation regions)

not explored; topic of the present talk

(2) RG corrections to the Higgs sector especially in the presence of a Seesaw (Significantly modifies the focus point regions)

(3) Through gauge corrections to the sleptonic fields (as they sit in the same multiplet as squarks) (modifies Co-annihilation regions)

Calibbi et. al, '06, '07, '10 Goto et. al, '07

Barger et.al, '08,'10 Gomez et.al ,'08,'09,'10

Olive et.al ,'08,'09,'10

The effect of LFV

(a) The mass of the lightest stau gets modified

(b) The cross sections get modified in the early universe because of the presence of flavour violation

Both these effects significantly modify the stau co-annihilation region

Flavour Effects in the co-annihilation region

In GUT theories like SU(5),

$$W = h^u_{ij} 10_i 10_j \bar{5}_H + h^d_{ij} 10_i \bar{5}_j 5_H + \ldots$$

RG running above the Grand Unified Scale Can give rise to Flavour Violation in the RR sector

$$(\Delta_{RR})_{i\neq j} = (m^2_{\tilde{10}})_{ij}(M_X \to M_{GUT})$$
$$= -3 \cdot \frac{3m_0^2 + a_0^2}{16\pi^2} V_{ti} V_{tj} \ln\left(\frac{M_X^2}{M_{GUT}^2}\right) h_t^2$$

Suppressed by CKM angles.

Limits from Flavour Violation much weaker

Left-Right Symmetric Models

Left Right symmetric models could have sizeable LFV in the RR sector

C. S.Aulakh et. al
'97 '98

$$\Delta m_L^2 = -\frac{1}{4\pi^2}(3f_c f_c^\dagger + Y_L Y_L^\dagger)(3m_0^2 + A_0^2)\ln\left(\frac{m_{\rm GUT}}{v_r}\right)$$

$$\Delta m_{L^c}^2 = -\frac{1}{4\pi^2}(3f_c^\dagger f_c + Y_L^\dagger Y_L)(3m_0^2 + A_0^2)\ln\left(\frac{m_{\rm GUT}}{v_r}\right)$$

Esteves et. al
arXiv: 1011.0348

However, LR symmetry forces same amount of LFV in the LL sector too !

$\delta \sim \mathcal{O}(10^{-1})$ could still be generated

Model Independent Approach

Assume $(\Delta)_{RR}$ (FN Models, moduli breaking etc)

The weak scale mass matrix $\Phi^T \mathcal{M}^2_{\tilde{l}} \Phi$ in the basis

$\Phi^T = \{\tilde{\mu}_L, \tilde{\tau}_L, \tilde{\mu}_R, \tilde{\tau}_L\}$ has the form :

$$\mathcal{M}^2_{\tilde{l}} = \begin{pmatrix} m^2_{\tilde{\mu}_L} & 0 & m^2_{\tilde{\mu}_{LR}} & 0 \\ 0 & m^2_{\tilde{\tau}_L} & 0 & m^2_{\tilde{\tau}_{LR}} \\ m^2_{\tilde{\mu}_{LR}} & 0 & m^2_{\tilde{\mu}_R} & \Delta^{\mu\tau}_{RR} \\ 0 & m^2_{\tilde{\tau}_{LR}} & \Delta^{\mu\tau}_{RR} & m^2_{\tilde{\tau}_R} \end{pmatrix}$$

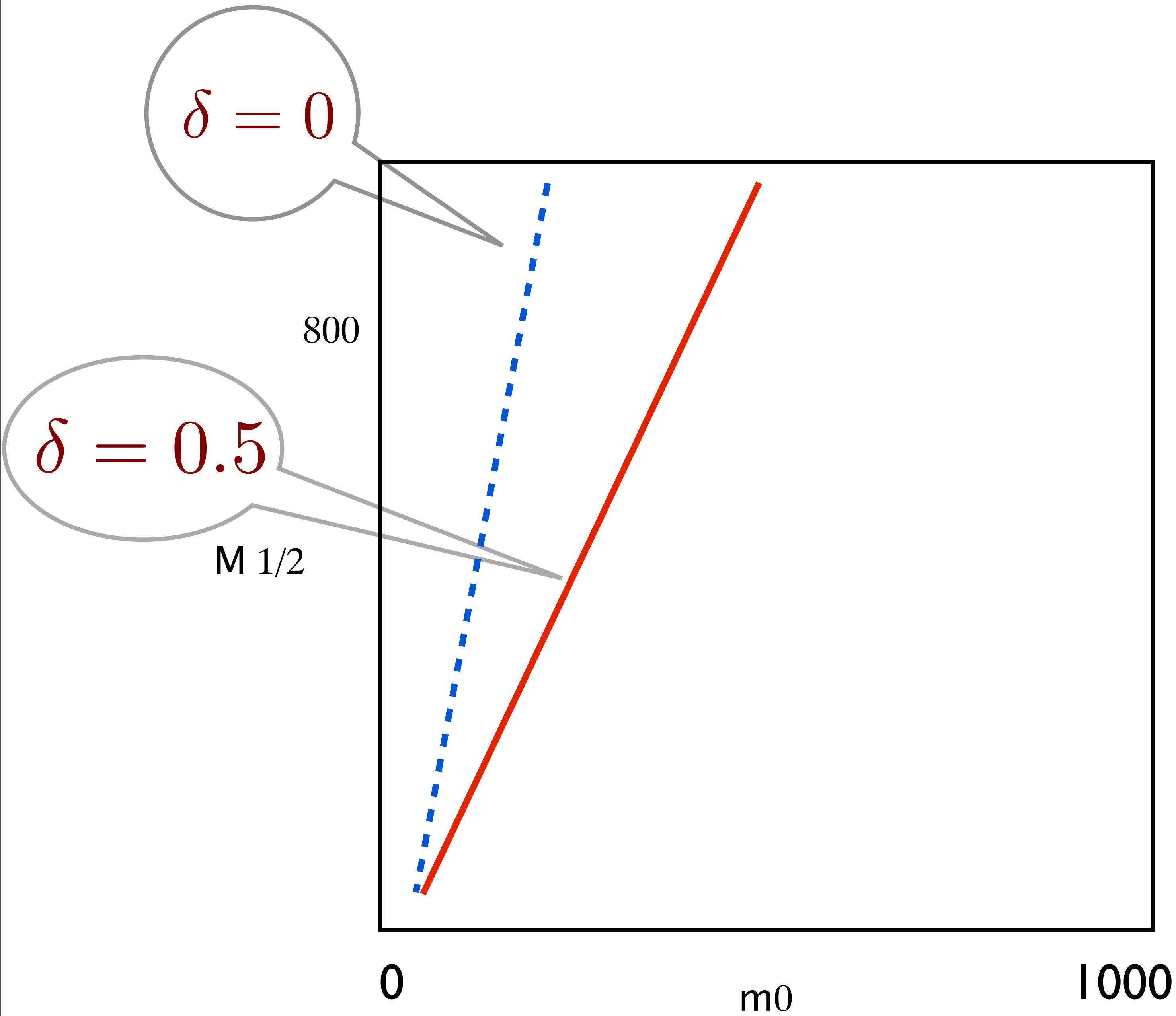
The lightest eigenvalue takes the form :

$$\boxed{m^2_{\tilde{\tau}_1} \approx m^2_{\tilde{\tau}_R}(1-\delta) - m_\tau \mu \tan\beta}$$

No tachyons

where $\delta = (\Delta_{RR})/m^2_{\tilde{\tau}_R}$

$$\delta < 1 - \frac{m_\tau \mu \tan\beta}{m^2_{\tilde{\tau}_R}}$$



The co-annihilation condition is given by

$$\boxed{m_{\tilde{\tau}_1} \approx M_{\chi_0^1}}$$

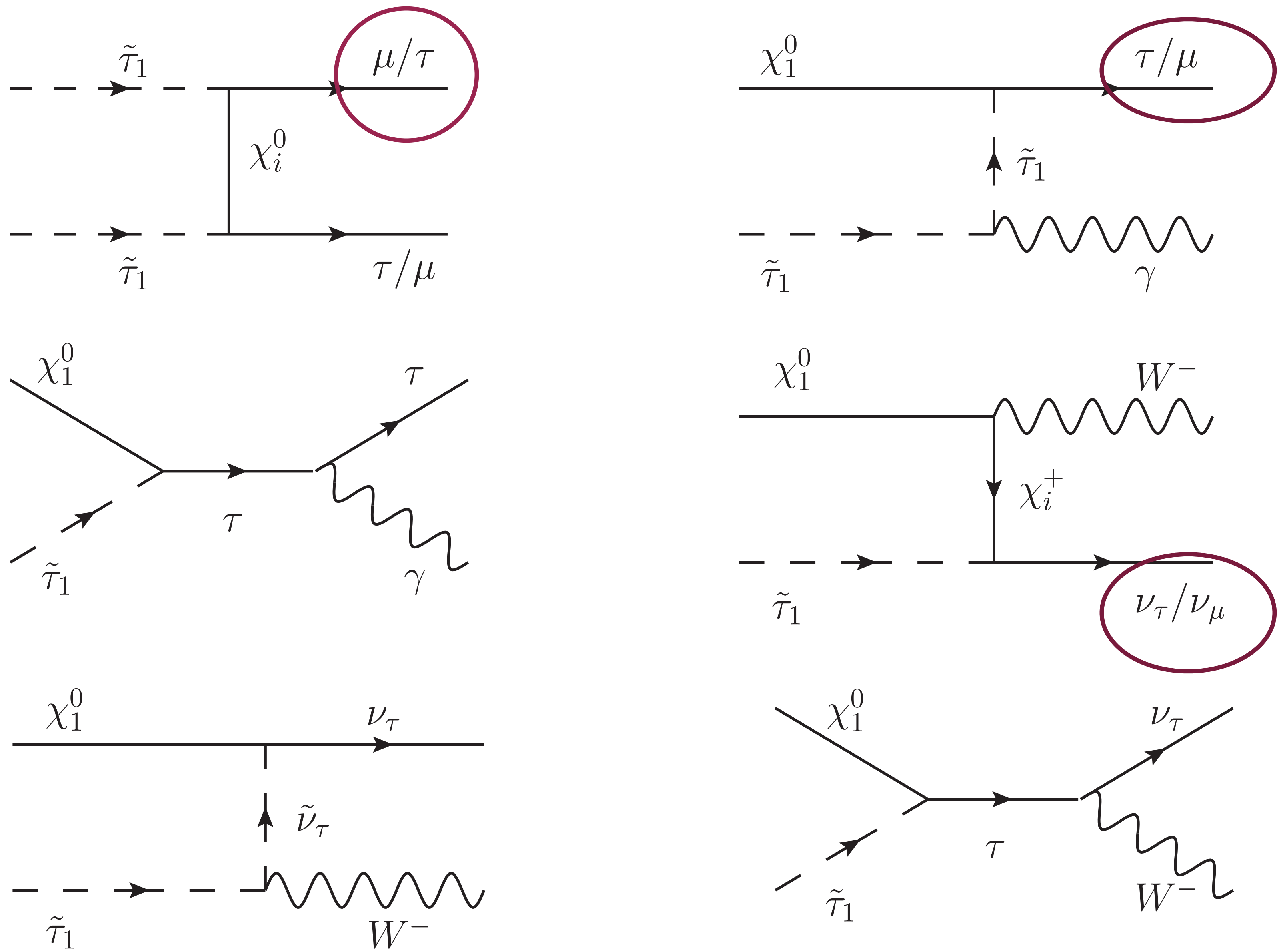
In terms of high energy parameters

Flavour Violation changes the slope, lowers the neutralino mass consistent with relic density

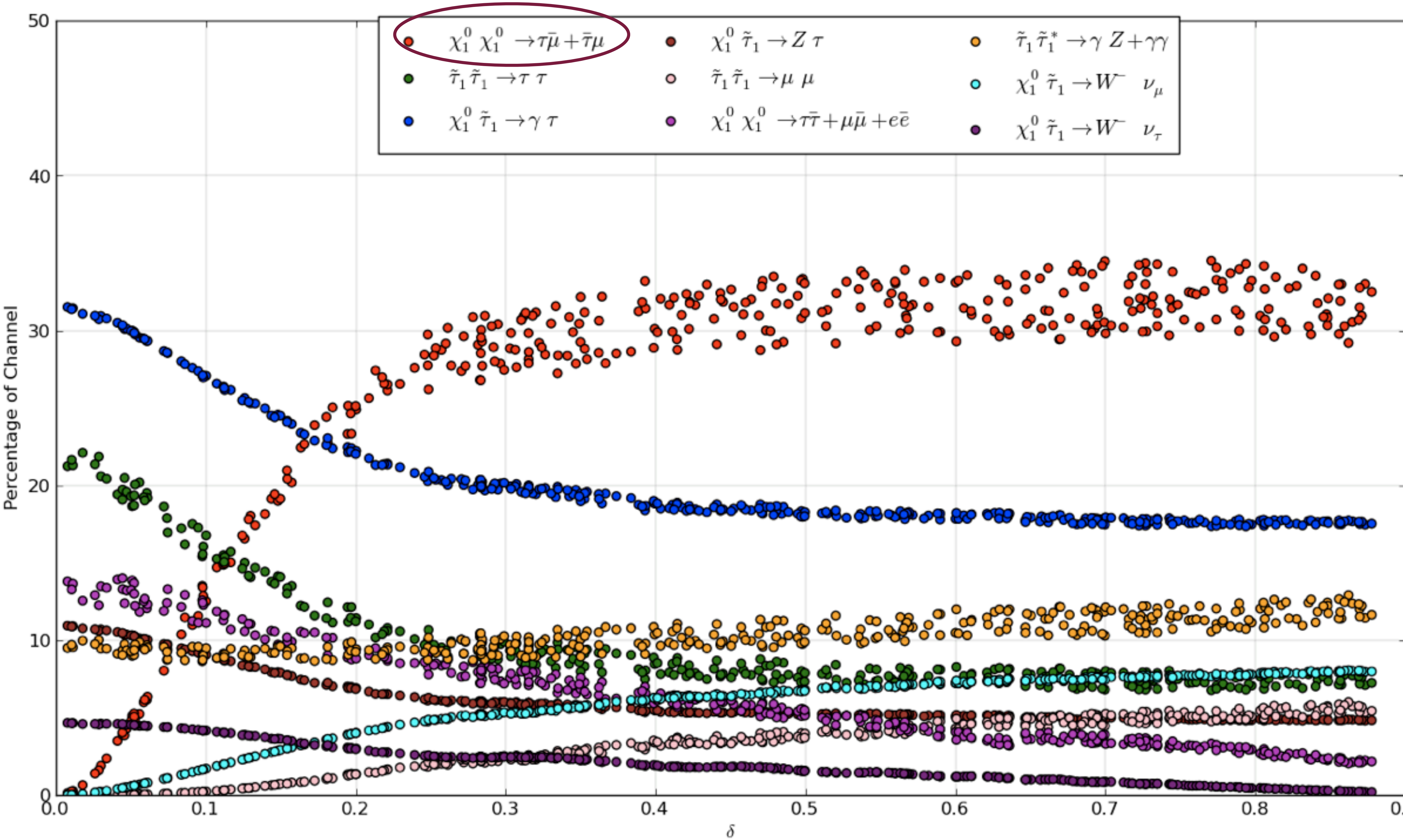
Neglecting flavour (and other) constraints for the time being..

Stau Co-annihilations in the presence of flavour violation

New Flavour violating processes could contribute to the scatterings in the early universe



Channels in Co-annihilation regions



Flavour violating channels become dominant

Choudhury, Garani, Vempati *1104.4467*

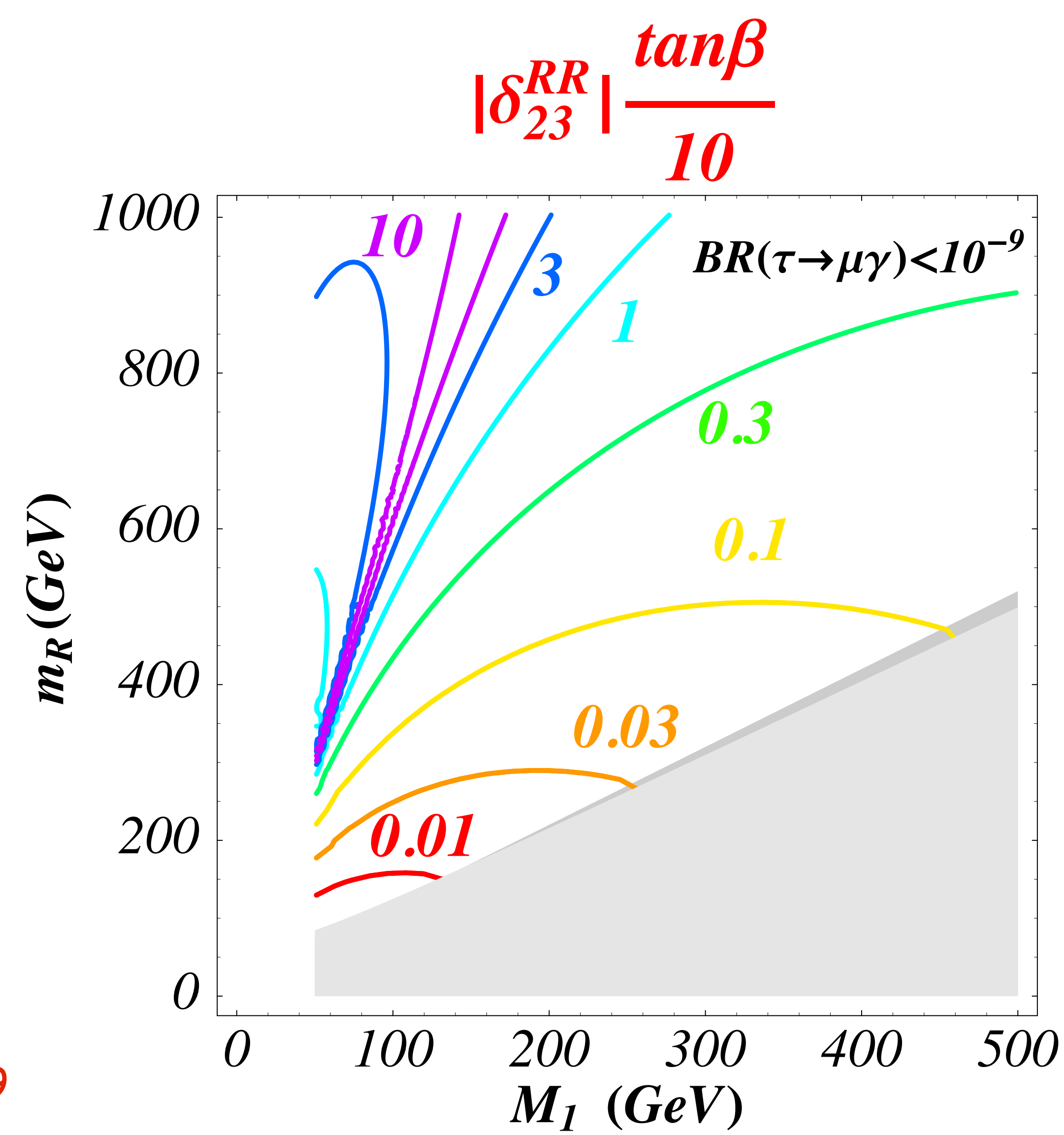
Flavour Constraints on RR Sector

* No Chargino Contributions

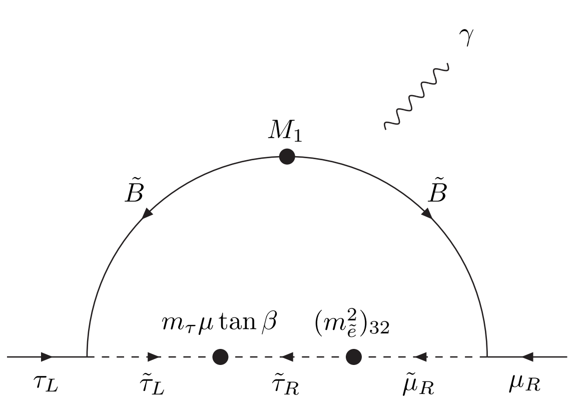
* Only Neutralino contributions

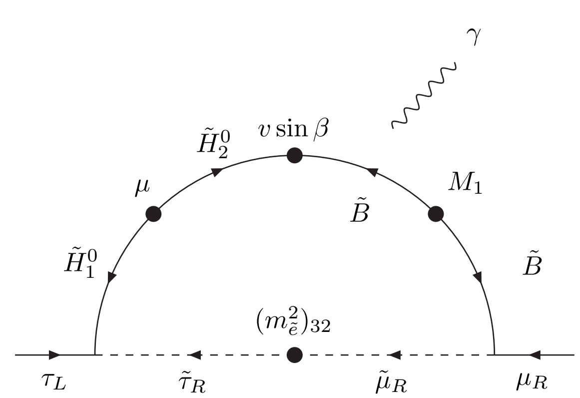
* Partial cancelations between the two contributions

Hisano et.al 96
Hisano Nomura 99
Paride 06
Ciuchini et.al 07

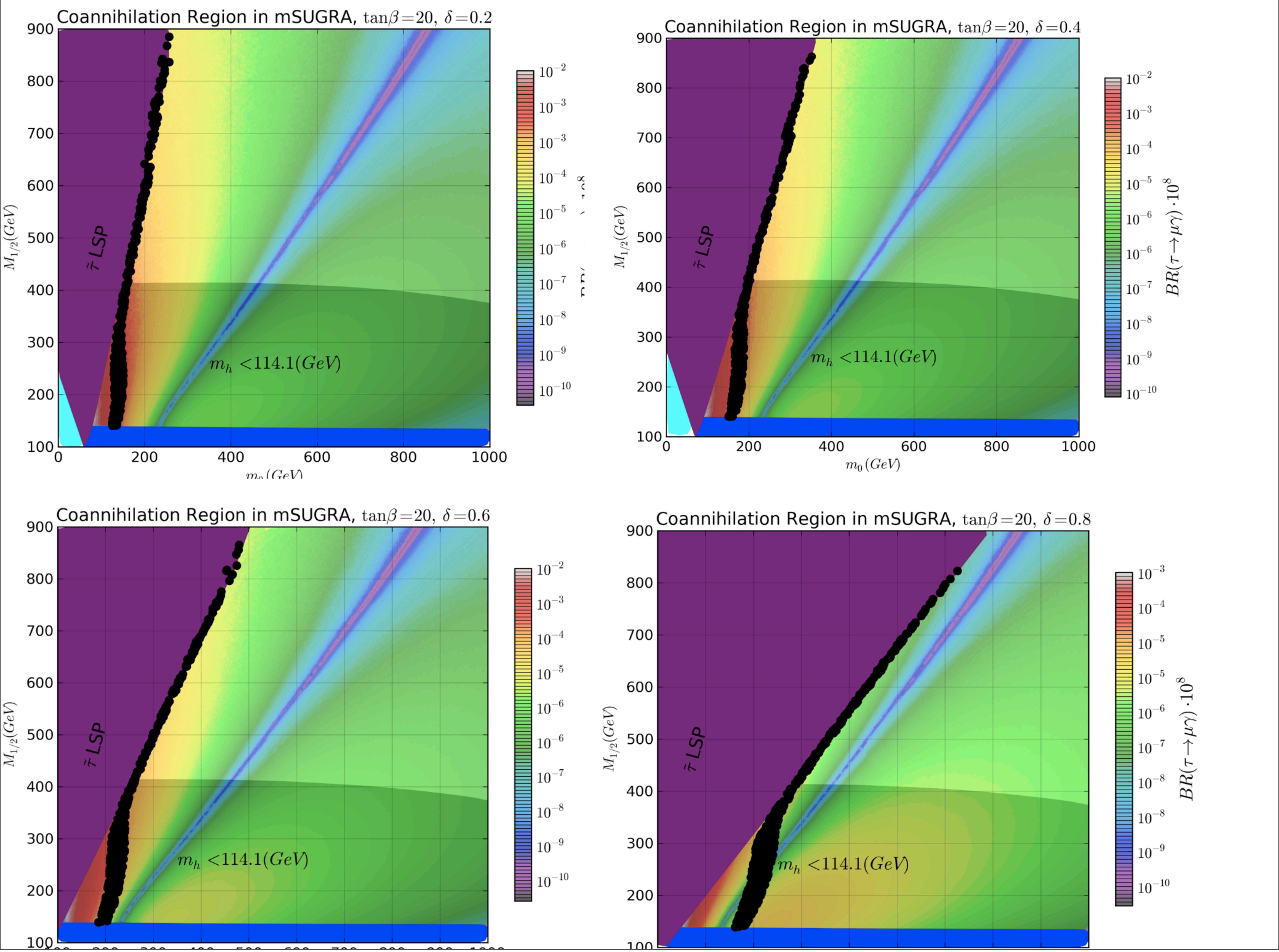


From Masina and Savoy, NPB '02





There is no overlap between both the regions in mSUGRA


Coannihilation Region in mSUGRA, $\tan\beta=20,\ \delta=0.2$
Coannihilation Region in mSUGRA, $\tan\beta=20,\ \delta=0.4$
Coannihilation Region in mSUGRA, $\tan\beta=20,\ \delta=0.6$
Coannihilation Region in mSUGRA, $\tan\beta=20,\ \delta=0.8$
$\tilde{\tau}$ LSP
$m_h < 114.1(GeV)$
$M_{1/2}(GeV)$
$m_0(GeV)$
$BR(\tau \to \mu\gamma)\cdot 10^8$

Relaxing the universality

* In GUT models like SO(10), all the matter sits in a single multiplet. It is likely that if soft masses are non-universal at origin, it would manifest in the higgs.

Consider NUHM with $m^2_{H^0_1} = m^2_{H^0_2}$

Overlap between regions where cancelations in flavour violation and regions with co-annihilations is now possible !

μ becomes a free parameter

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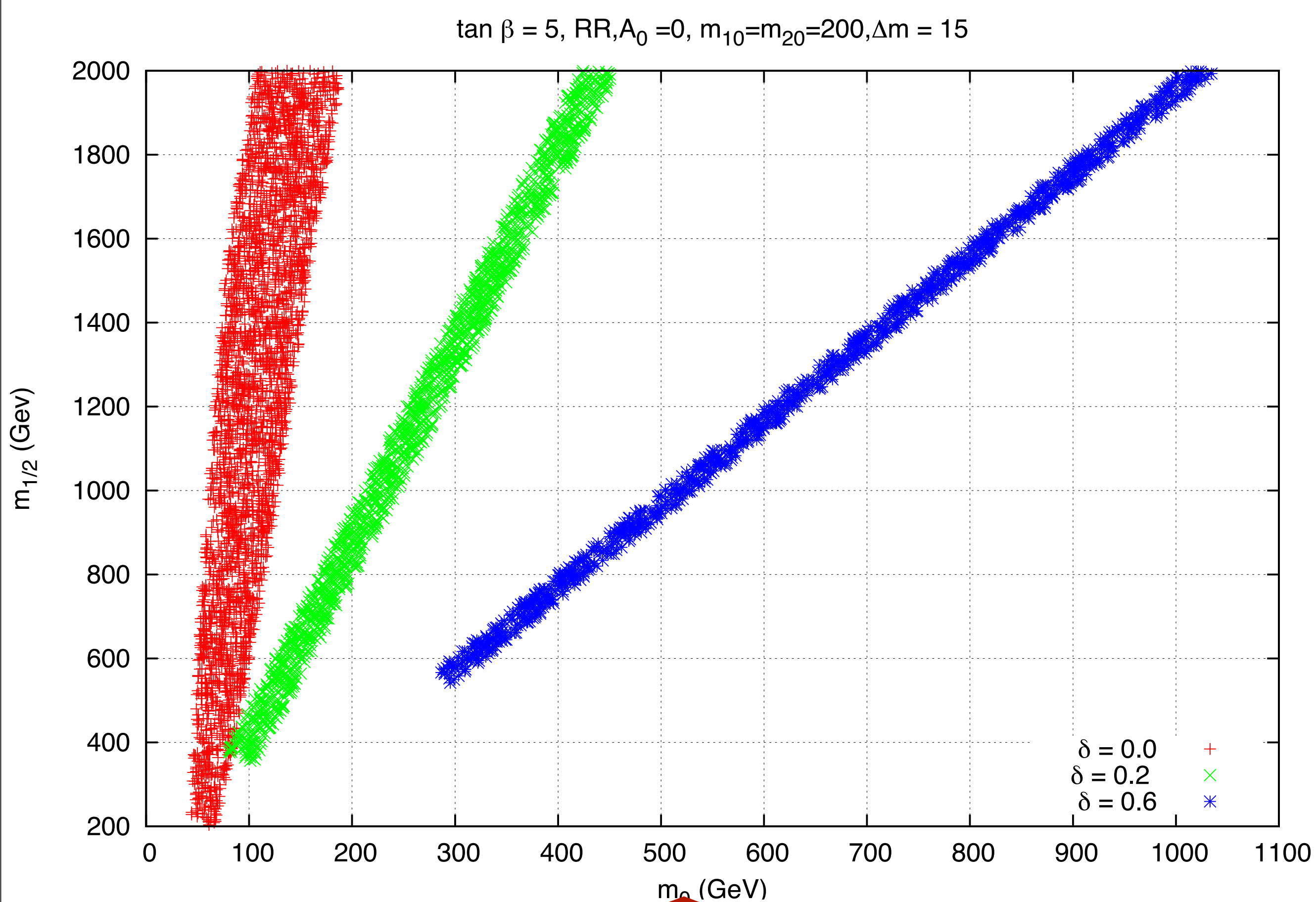
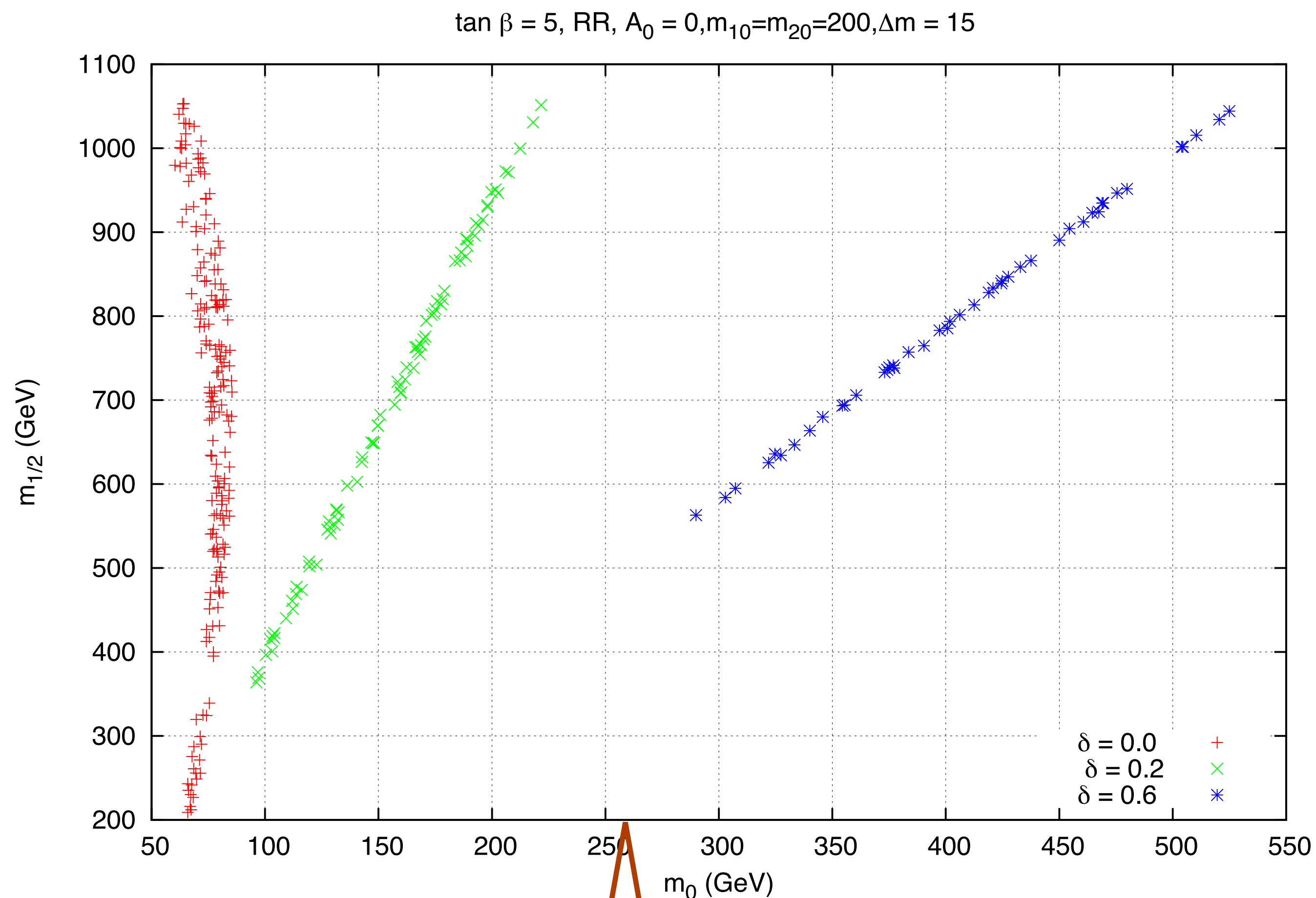
NUHM model

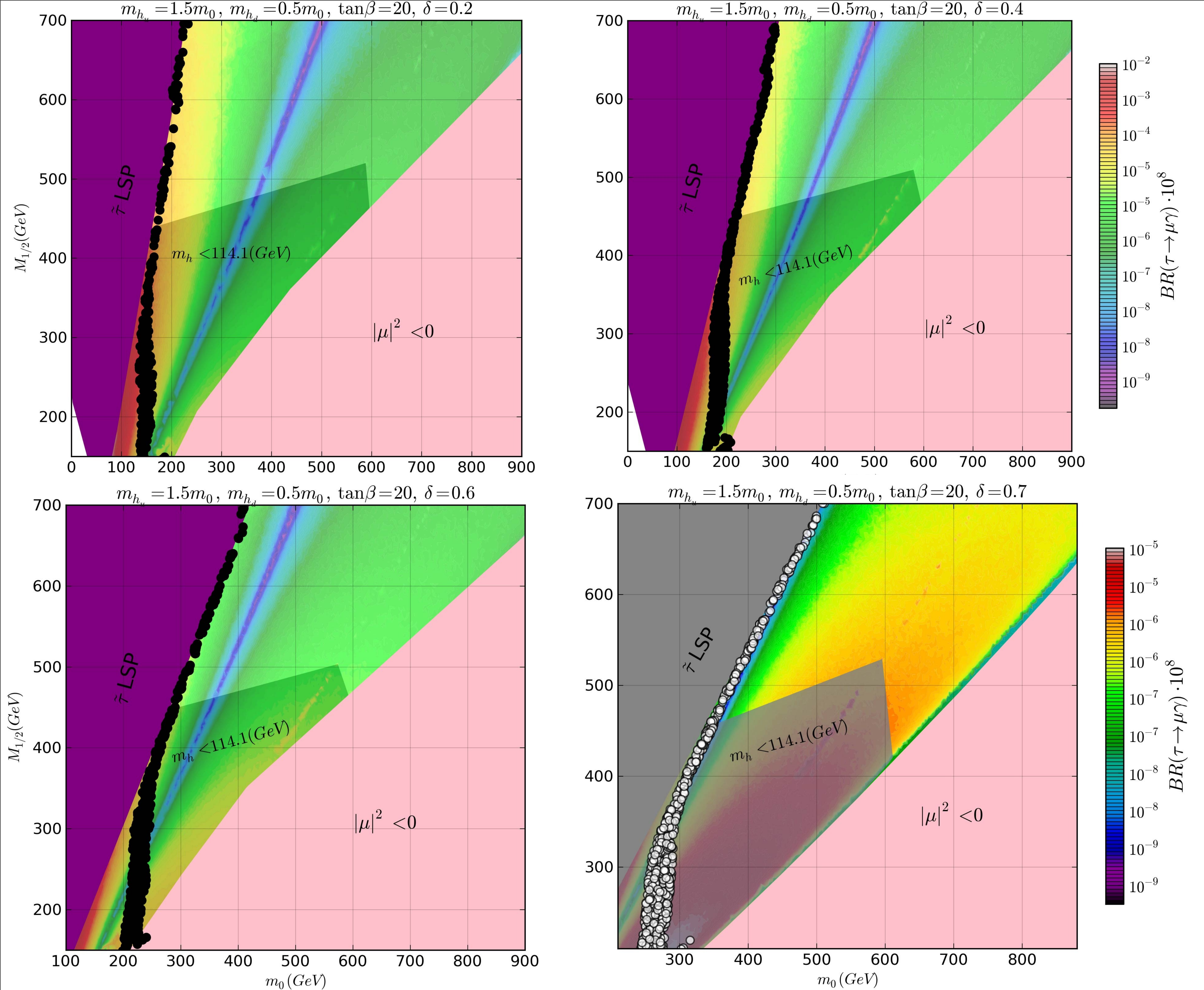




Imposing all constraints except flavour violation

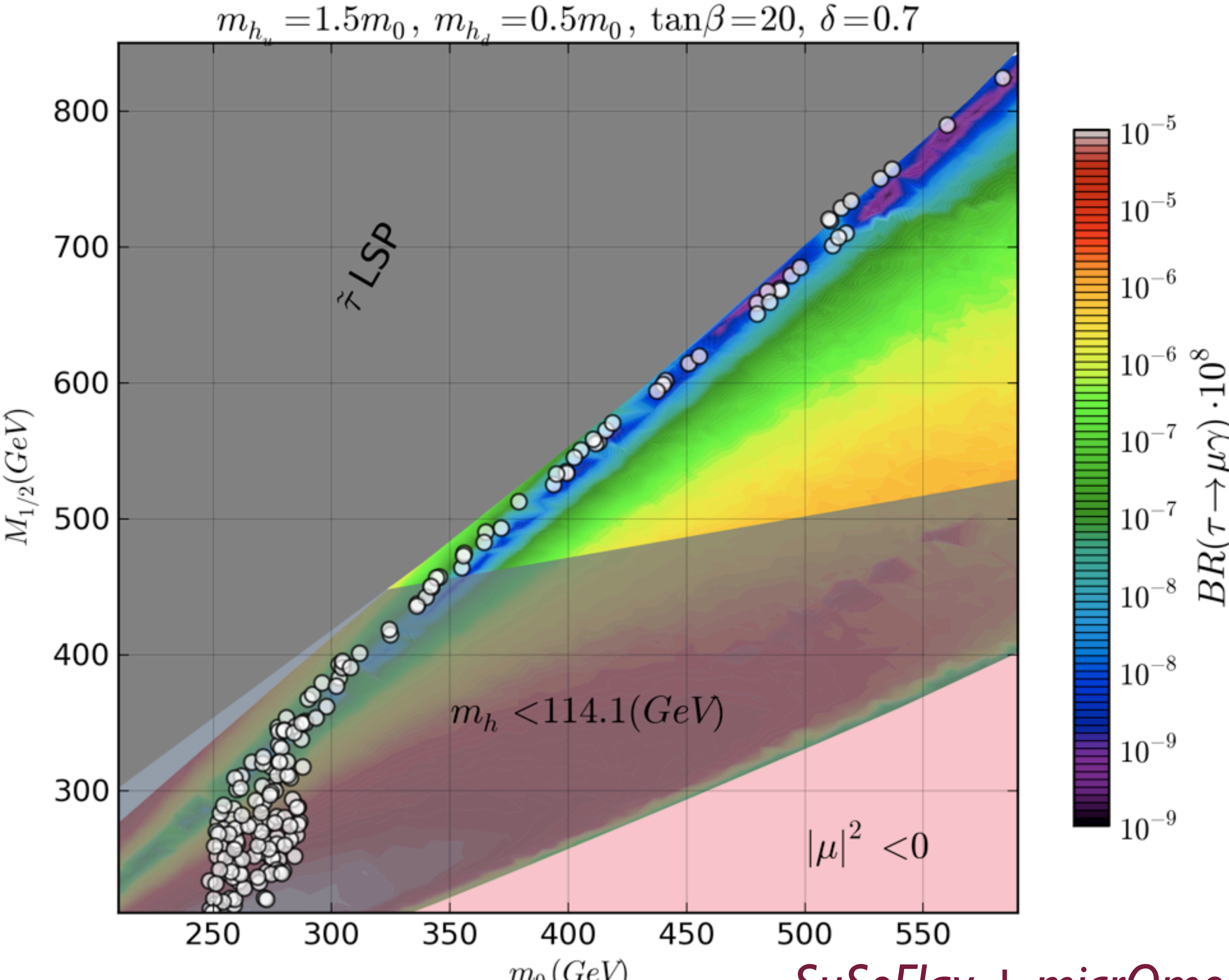
Including flavour violating constraints

$$\mathrm{Br}(\tau \to \mu + \gamma) < 2 \times 10^{-8}$$

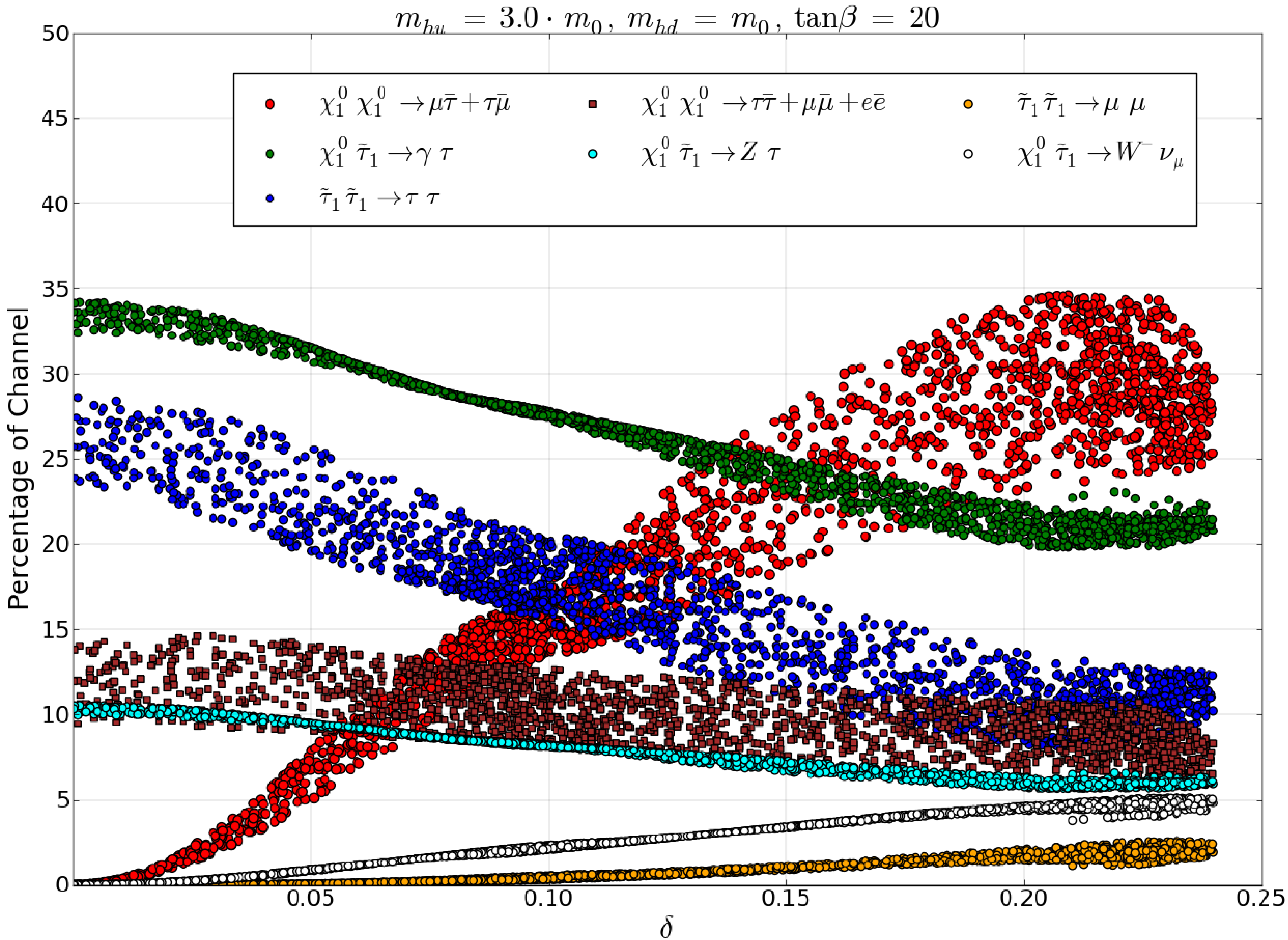

$m_{h_u}=1.5m_0$, $m_{h_d}=0.5m_0$, $\tan\beta=20$, $\delta=0.2$
$m_{h_u}=1.5m_0$, $m_{h_d}=0.5m_0$, $\tan\beta=20$, $\delta=0.4$
$m_{h_u}=1.5m_0$, $m_{h_d}=0.5m_0$, $\tan\beta=20$, $\delta=0.6$
$m_{h_u}=1.5m_0$, $m_{h_d}=0.5m_0$, $\tan\beta=20$, $\delta=0.7$
$\tilde{\tau}$ LSP
$m_h<114.1(GeV)$
$|\mu|^2<0$
$M_{1/2}(GeV)$
$m_0(GeV)$
$BR(\tau\to\mu\gamma)\cdot 10^8$

Choudhury, Garani, Vempati *1104.4467*

Flavoured Coannihilations in NUHM



SuSeFlav + micrOmegas



Regions with smaller delta also
can be found

Summary of Flavour effects

Large flavour violation if present in the RR sector can modify significantly the co-annihilation region both in spectrum and relic density calcluations

Extensions of mSUGRA like NUHM have interesting regions with *flavoured co-annihilations*

Low tanbeta is more preferable compared to high tanbeta as the amplitudes increases as tanbeta

A. Datta et. al
Gomez et. al

We expect the regions to give interesting lepton flavour violating signals at LHC/ILC